# AN AGENT-BASED ARCHITECTURE FOR MOBILITY MANAGEMENT IN INTERNET PROTOCOL NETWORKS

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# DEDICATION

To my beloved mother and father,
for their un-diminishing love, support and understanding

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**In the Name of Allah, Most Gracious, Most Merciful**

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# ABSTRACT

Mobility is afforded by the degree of intelligence or control mechanism in the network for mobility management. In cellular architectures, intelligence is explicitly integrated into the core network resulting in an efficient service with low latencies but a complex architecture with high deployment and operational costs. The Internet's approach for mobility is simpler with intelligence placed in end-systems and certain specialised nodes, conforming to the Internet's principle of the end-to-end arguments. However, the drawbacks include latencies and packet loss, which have hindered its wide-scale deployment. The research here proposes to address these perplexities by using an approach that enhances mobility management. The main objective is to develop an architecture that exhibits dynamism and improved IP-based mobility but without added complexity in the network core. The proposed architecture, called agent-based mobility protocol (AMP) is a collaborative multi-agent system residing in mobile hosts and access networks that facilitates and expedites location and handover management. In developing the AMP architecture, the agency for the mobile host was firstly specified and built using an agent development platform. Next, the heart of AMP architecture i.e. the access network agency was designed and implemented over the network simulator ns-2. The performance of AMP was evaluated based on both derived mathematical and simulation models and compared against Mobile IPv6 with varying call-mobility ratios. Mathematical results indicate that AMP outperformed Mobile IPv6 with an average of 86% lower signaling cost and 85% less handover delay. Simulation results show that AMP reduces packet delay by 39% and packet loss by 48%. Thus, with AMP, an improved IP-based mobility may be achieved through added intelligence but without the necessary complexity in the core. Furthermore, AMP may be well suited for micro-mobility and may give better support for real-time applications.

# ABSTRAK

Kemudahan mobiliti dari sesuatu rangkaian bergantung kepada kecerdasan atau mekanisma kawalan terhadap pengurusannya. Dalam rangkaian selular, kecerdasan menjadi sebahagian struktur teras rangkaian tersebut. Pendekatan ini menghasilkan perkhidmatan mobiliti yang efisien tetapi struktur kompleks dengan kos yang tinggi. Pendekatan Internet lebih mudah di mana kercerdasan hanya melibatkan beberapa elemen di hujung sistem rangkaian, selaras dengan prinsip Internet hujung-ke-hujung. Walaubagaimanapun, kaedah ini mengakibatkan kelewatan dan kehilangan data yang tinggi dan ini menjejaskan penggunaannya secara meluas. Oleh itu, tesis ini mempelopori suatu pendekatan baru yang dapat meningkatkan perkhidmatan mobiliti. Objektif utama ialah untuk menghasilkan suatu struktur yang dapat menawarkan perkhidmatan IP-mobiliti yang lebih dinamik dan cerdas tanpa melibatkan struktur yang kompleks dalam teras rangkaian. Sistem yang dikenali sebagai protokol mobiliti berasaskan agen (AMP) terdiri dari sistem pelbagai-agen, terletak di perumah bergerak dan rangkaian akses, yang bekerjasama untuk memudahkan dan meningkatkan tahap kecerdasan untuk pengurusan lokasi dan ambil-alih. Sistem agen ini mula dibina pada perumah bergerak dengan menggunakan suatu pelantar pembinaan agen. Ini disusuli dengan merekabentuk dan membina sistem agen di akses rangkaian menggunakan komputer simulasi rangkaian ns-2. Pencapaian AMP dikaji dari dua segi – analisis matematik dan model simulasi, dan dibandingkan dengan Mobile IPv6 menggunakan nisbah panggilan-mobiliti yang berbeza. Hasil analisis matematik menunjukkan AMP menandingi Mobile IPv6 dengan 86% kurang kos pengisyaratan dan 85% kurang kelewatan ambil-alih. Hasil simulasi pula menunjukkan AMP mengurangkan 39% kelewatan paket dan 48% kehilangan paket. Oleh itu, AMP dapat menawarkan peningkatan dalam perkhidmatan mobiliti tanpa melibatkan struktur yang kompleks. Tambahan pula, AMP mungkin lebih sesuai untuk mobiliti mikro dan dapat menampung aplikasi yang bercorak masa-sebenar.

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| | | |
|---|---|---|
| 3G | – | 3rd Generation Network |
| Ack | – | Acknowledgement |
| AMP | – | Agent-based Mobility Protocol |
| AMPAR | – | AMP Access Router |
| AMPBS | – | AMP Base Station |
| AMPMH | – | AMP Mobile Host |
| AMPS | – | Advanced Mobile Phone System |
| AN | – | Access Network |
| AR | – | Access Router |
| ARP | – | Address Resolution Protocol |
| ATM | – | Asynchronous Transfer Mode |
| B-ISDN | – | Broadband ISDN |
| BAck | – | Binding Acknowledgement |
| BS | – | Base Station |
| BSC | – | Base Station Controller |
| BSSGP | – | Base Station SubSystem GPRS Protocol |
| BR | – | Binding Refresh |
| BT | – | British Telecom |
| BTS | – | Base Transceiver Station |
| BU | – | Binding Update |
| CBR | – | Constant Bit Rate |
| CBQ | – | Class-Based Queueing |
| CDPD | – | Cellular Digital Packet Data |
| CGI | – | Cell Global Identity |
| CH | – | Correspondent Host |
| CKSN | – | Ciphering Key Sequence Number |
| CLNS | – | ConnectionLess Network Services |

| | | |
|---|---|---|
| CMR | – | Cost-Mobility Ratio |
| CMU | – | Carnegie Mellon University |
| CN | – | Correspondent Network |
| CoA | – | Care-of-address Agent |
| CoT | – | Care-of-address Test |
| CoTI | – | Care-of-address Test Init |
| CONS | – | Connection Oriented Network Services |
| CPU | – | Central Processing Unit |
| DAD | – | Duplicate Address Detection |
| DHCP | – | Dynamic Host Control Protocol |
| EDGE | – | Enhanced Data Rates for GSM Evolution |
| EGPRS | – | Enhanced GPRS |
| EIR | – | Equipment Identity Register |
| ETSI | – | European Telecommunications Standards Institute |
| FA | – | Foreign Agent |
| GPRS | – | General Packet Radio Services |
| GGSN | – | Gateway GPRS Support Node |
| GSM | – | Global System for Mobile Communications |
| GSN | – | GPRS Support Node |
| GTP | – | GPRS Tunneling Protocol |
| HA | – | Home Agent |
| HoT | – | Home Agent Test |
| HoTI | – | Home Agent Test Init |
| HLR/GR | – | Home Location Register/GPRS Register |
| HSCSD | – | High Speed Circuit Switched Data |
| IETF | – | Internet Engineering Task Force |
| ICMP | – | Internet Protocol: Error and Control Messages Protocol |
| IMT2000 | – | International Mobile Telecommunications in the year 2000 |
| IMSI | – | International Mobile Subscriber Identity |
| IN | – | Intelligent Network |
| IP | – | Internet Protocol |
| $IP_{CO}$ | – | Co-located (temporary) IP address |
| $IP_{COnet1}$ | – | Co-located (temporary) IP address at access network 1 |
| $IP_H$ | – | Home network registrar's IP address |

| | | |
|---|---|---|
| $IP_{MH}$ | – | Mobile host’s permanent IP address |
| $IP_{RV}$ | – | Visited registrar’s IP address |
| $IP_{Tj}$ | – | Tracker’s IP address at *j* cell/subnet |
| IP-M | – | IP Multicast |
| IPv4 | – | Internet Protocol version 4 |
| IPv6 | – | Internet Protocol version 6 |
| ISDN | – | Integrated Services Digital Network |
| ITU | – | International Telecommunications Union |
| IWU | – | InterWorking Unit |
| L2 | – | Link Layer |
| L3 | – | Network Layer |
| LAN | – | Local Area Network |
| LBNL | – | Lawrence Berkeley National Lab |
| LLC | – | Logical Link Control |
| LS | – | SIP Location Server |
| MAC | – | Media Access |
| MDP | – | Mobility Dependent Predictive service class |
| ME | – | Mobile Equipment |
| MH | – | Mobile Host |
| MIG | – | Mobility Independent Guaranteed service class |
| MIP | – | Mobile IP |
| MIPSC | – | Mobility Independent Predictive Service Class |
| MM | – | Mobility Management |
| mQoS | – | mobile Quality of Service |
| MS | – | Mobile Station |
| MSC | – | Mobile services Switching Centre |
| NA | – | Neighbour Advertisement |
| N-ISDN | – | Narrowband ISDN |
| NS | – | Neighbour Solicitation |
| ns-2 | – | Network Simulator version 2 |
| opt | – | ns-2 global options in Tcl |
| OTcl | – | Object-oriented Tcl |
| P-TMSI | – | Packet Temporary Mobile Subscriber Identity |
| PARC | – | Palo Alto Research Center |

| | | |
|---|---|---|
| PC | – | Personal Computer |
| PCS | – | Personal Communications Services |
| PCU | – | Packet Control Unit |
| PDA | – | Personal Digital Assistant |
| PDC | – | Personal Digital Cellular |
| PDCH | – | Packet Data CHannel |
| PDP | – | Packet Data Protocol |
| PDN | – | Packet Data Network |
| PDU | – | Protocol Data Unit |
| PLMN | – | Public Land Mobile Network |
| POTS | – | Plain Old Telephone System |
| PPP | – | Point-to-Point Protocol |
| PSTN | – | Public Switched Telephone Network |
| PTM | – | Point-To-Multipoint packet services |
| PTM-G | – | PTM Group call |
| PTM-M | – | PTM Multicast |
| PTP | – | Point-To-Point packet services |
| QoS | – | Quality of Service |
| RA | – | Routing Area |
| RAd | – | Router Advertisement |
| RAI | – | Routing Area Identity |
| RD | – | Router Discovery |
| RED | – | Random Early Discard |
| RFC | – | Request For Comment |
| Rg | – | Registrar agent |
| RR | – | Return Routability |
| RS | – | Router Solicitation |
| RSVP | – | Resource reSerVation Protocol |
| RTCP | – | Real-Time Control Protocol |
| RTP | – | Real-Time Protocol |
| RTTP | – | Real-Time Transmission Protocol |
| SAP | – | Session Announcement Protocol |
| SDP | – | Session Description Protocol |
| SGSN | – | Serving GPRS Support Node |

| | | |
|---|---|---|
| SIM | – | Subscriber Identity Module |
| SIP | – | Session Initiation Protocol |
| SLIP | – | Serial Line IP |
| SMS | – | Short Messaging Services |
| SR | – | SIP Registrar |
| SS | – | SIP Server |
| SS7 | – | Signaling System 7 |
| T | – | Tracker agent |
| $Tb_{1j}$ | – | Border tracker agent at access network 1 cell/subnet *j* |
| TCP | – | Transmission Control Protocol |
| TCP/IP | – | Transmission Control Protocol/Internet Protocol |
| TID | – | Tunnel Identifier |
| TTLI | – | Temporary Logical Link Identity |
| UAC | – | SIP User Agent Client |
| UAS | – | SIP User Agent Server |
| UDP | – | User Datagram Protocol |
| UMTS | – | Universal Mobile Telecommunications Service |
| USIM | – | User Services Identity Module |
| VBR | – | Variable Bit Rate |
| VHE | – | Virtual Home Environment |
| VINT | – | Virtual InterNetwork Testbed |
| WAN | – | Wide Area Network |
| WAP | – | Wireless Application Protocol |
| WLAN | – | Wireless Local Area Network |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A_c$ | – | Cell area |
| $C_{hc}$ | – | Binding update cost at home (*h*) and correspondent (*c*) networks |
| $C_{x,y}$ | – | Transmission cost of control packets between nodes *x* and *y* |
| $C_{BU}$ | – | Signaling cost for address binding update |
| $C_{BR}$ | – | Signaling cost for refreshing existing address binding |
| $C_{fwdg}$ | – | Signaling cost of forwarding duplicate packets to the next network |
| $C_{loss}$ | – | Signaling cost for packet loss |
| $C_{PD}$ | – | Signaling cost for packet delivery |
| $C_T$ | – | Total signaling overhead cost |
| $D_{handover}$ | – | Total handover latency |
| $D_{intra}$ | – | Handover latency for intra-network movement |
| $D_{inter}$ | – | Handover latency for inter-network movement |
| $E(N)$ | – | Mean number of location bindings or registrations during an inter-session arrival |
| $f_c$ | – | Probability density function of $t_c$ |
| $f_n$ | – | Probability density function of $t_n$ |
| $G$ | – | Global binding update cost sent to the home network or correspondent network |
| $h_{x,y}$ | – | Number of hops between nodes *x* and *y* |
| $K$ | – | Number of correspondent network registrars having a binding cache entry for an *MH* |
| $K_{CN}$, $K_{CH}$ | – | Number of correspondent networks, or correspondent hosts, having a binding cache entry for an *MH* |
| $L$ | – | Local binding update cost sent to the local registrar |
| $M$ | – | Number of cells/subnets within an access network |

| | | |
|---|---|---|
| $N_c$ | – | Number of cells/subnets crossing within an access network during intra-network handoff |
| $N_n$ | – | Number of access networks crossing during inter-network handoff |
| $p$ | – | Probability of wireless link failure |
| $P_c$ | – | Cell crossing probability |
| $P_{loss}$ | – | Packet loss |
| $P_n$ | – | Network crossing probability |
| $P_s$ | – | Probability of anticipated handoff signaling success |
| $PC_x$ | – | Processing cost of control packet at node $x$ |
| $R_{wired}$ | – | Wired link bandwidth |
| $R_{wireless}$ | – | Wireless link bandwidth |
| $S_{actual}$ | – | Actual buffer space |
| $S_{req}$ | – | Required buffer space |
| $t_c$ | – | Random variable for *MH*'s cell/subnet residence time |
| $t_{DAD}$ | – | Delay for duplicate address detection |
| $t_{GU}$ | – | Global binding update delay |
| $t_{L2}$ | – | Time period between link layer (L2) trigger to link switching. |
| $t_{IP}$ | – | IP connectivity delay |
| $t_{LU}$ | – | Local binding update delay |
| $t_n$ | – | Random variable for the residence time within an access network |
| $t_{queue}$ | – | Average queueing delay at each router hop |
| $t_{RD}$ | – | Round-trip delay for router discovery |
| $t_{RR}$ | – | Delay for router routability procedure |
| $t_{rs}$ | – | *MH* residual subnet residence time |
| $t_s$ | – | Inter-session time between two consecutive sessions with PDF $f_s$ |
| $t_{wired}$ | – | Wired link delay |
| $t_{wireless}$ | – | Wireless link delay |
| $t_{x,y}$ | – | One-way transmission delay between nodes $x$ and $y$ |
| $\sigma$ | – | Parameter for success rate |

| | | |
|---|---|---|
| $\delta$ | – | Weighing factor for packet forwarding |
| $\varsigma$ | – | Weighing factor for packet loss |
| $\lambda$ | – | Packet arrival rate (Poisson) |
| $\eta$ | – | Ratio of average signaling control packet length to the average data packet length |
| $\Gamma$ | – | Binding lifetime period |
| $\Gamma_x$ | – | Binding lifetime period at network *x* |
| $\mu_c$ | – | *MH* movement (border crossing) rate out of a cell/subnet |
| $\mu_l$ | – | *MH* movement (border crossing) rate in which *MH* still stays within the same access network |
| $\mu_n$ | – | *MH* movement (border crossing) rate out of an access network |
| $\nu$ | – | Average velocity of a mobile host |
| $\chi_T$ | – | Random variable for the time between link layer trigger generation and link down |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

As the cost of computing power decreases, and information becomes more accessible on a global scale, the demand for efficient and reliable delivery of information becomes increasingly apparent. With the growth of the web, such information is no longer restricted to bursty data, but encompasses voice, image, and video. In the enterprise environment, multimedia rich applications integrating voice, e-mail, internal web and video have found their way into corporate networks. In addition, many organisations view real time information as an integral part of their mission critical applications, and these too may include a combination of data (such as stock quotes), voice and video.

At present, the *Internet Protocol*, IP, seems to be the most prevalent network layer technology for the Internet. Trends in the telecommunications industry seem to indicate a general direction where IP will most probably continue to be the dominant network layer technology for the delivery of information over the Internet. The large installation base of IP networks in the Internet means that this trend will most likely continue in the foreseeable future. However, IP has been a traditionally best-effort service, designed mainly for data delivery. To enable everything over IP (as in a multi-service network) and/or to run IP over everything (i.e. lower layer technologies) would require certain enhancements either to the protocol itself, or by some other means which would augment existing methods for improved delivery of information.

As a natural consequence of advancement in technology, decreasing cost of hardware, and the ever growing popularity of the World Wide Web, a significant number of clients have become mobile through the extensive use of laptops, handheld PCs and other personal communicating devices such as Personal Digital Assistants (PDAs), smart mobile phones etc. At present, access to the web and corporate Intranets for mobile subscribers has been facilitated by wireless means over the cellular environment. In addition, nomadic computing, a cheaper albeit restrictive definition of mobility, has been made possible by the proliferation of WiFi hotspots based on the IEEE 802.11 Wireless LAN standard. Moreover, it is anticipated that in the not-too-distant future, servers may also require some form of mobility. With mobility, people and even services are no longer restricted to a particular physical location in order to be reachable or accessible. Some plausible scenarios include:

- a commuter on a train, equipped with a mobile computing device, connects to the corporate Intranet or surfs the web;
- a mobile user making a unicast or multicast video-conferencing call; or
- a mobile user requiring ubiquitous connectivity – the ability to maintain a single session of communication over some network (not necessarily with the same device) throughout the duration of the connection.

The ability to provide mobility services is accorded by the mobility management scheme of a particular network. Mobility management entails location and handover management. The first refers to the ability of the network to maintain the location of roaming hosts or subscribers, while the latter refers to the ability of the network to maintain any ongoing connection while the host or subscriber moves to a different location or subnet. Generally, the more complex the mechanism for mobility management i.e. the level of network ‘intelligence’, the more efficient is the mobility service provided in terms of lower latencies and packet loss.

## 1.2 Problem Statement

The concept of mobility has always been appealing to many ever since the invention of the mobile phone some twenty years ago. The phenomenal growth of the cellular phone industry has illustrated the popularity of the mobile form of communication to users. Micro-mobility has been mainly for voice communication in the cellular environment. Internet-based mobility has been limited to macro-mobility (infrequent movement) or restricted services.

Seamless mobility is afforded by the provision of mobility management in the network. The ability to provide efficient support for mobility management relies on the degree of intelligence and the mechanisms by which this intelligence, or control information, is conveyed to the appropriate network nodes or entities, and the corresponding actions taken by those nodes.

The Internet differs significantly from cellular networks on how this is accomplished. The notion of mobility in the Internet is typically hidden from the IP network, and any intelligence in facilitating mobility management is restricted to end systems and certain specialised nodes or mobility agents i.e. an end-system-centric approach.

This is the approach adopted by the IETF's (Internet Engineering Task Force) Mobile IPv6 protocol, RFC 3775 (Johnson, 2004). The main advantage is simplicity, which translates to lower deployment cost and relative ease of operations. However, the drawbacks include variable delay, contention of resources and consequently, the inability to provide timing and bandwidth guarantees resulting in service degradation i.e. packet loss and high latencies. Not surprisingly, these factors have hindered the wide-scale deployment of Mobile IP.

In a sharp contrast, network intelligence is integrated explicitly in cellular networks for mobility management i.e. a network-centric approach. Extensive collaboration exists between network entities, both in the core and at the edges of the network, to accommodate and facilitate location and handover management. In addition, signaling and other control information to ensure call delivery and quality of transmission is done out-of-band ensuring efficient and reliable transmission with low latencies and minimal loss for mobile subscribers. However, the overheads in such systems are complexity, and higher deployment and operational costs to service providers. Additionally, the introduction of new services and solutions entails considerable time and planning As a consequence, these factors translate to higher service cost for subscribers.

Hence, the research here proposes to address these perplexities by adopting an approach that takes advantage of both of the above for the purpose enhancing Internet mobility. This would entail developing a mobile-aware host that works in conjunction with a more intelligent IP network that can adapt dynamically for the benefit of the mobile host.

The proposed work would address this issue by investigating and developing methods that will allow awareness of mobility in the mobile host as well as at the access networks. Subsequently, the research will explore methods of adaptation towards mobility through the use of distributed intelligence, via software agents, without adding complexity in the core of the IP network architecture. In all cases, mobility management will be developed primarily at the network-layer, thus maintaining transparency at the application- and link-layers of the protocol stack.

## 1.3 Aim and Objectives

The main aim of this research is to develop an architecture consisting of a collaborative multi-agent system that will facilitate and improve user/host mobility over a packet (IP)-based network. The research is centred on providing intelligence for more efficient support of mobility where user movement is relatively continuous during an application session. In essence, the objectives of the thesis may be stated as follows:

i) to define, design and develop an agent-based architecture over an IP-based network that will enable support for mobility management;
ii) to define and design a set of protocols that will facilitate and improve user mobility over the standard IETF's Mobile IPv6 protocol, whilst preserving application- and lower-layer transparency; and
iii) to evaluate the feasibility of the proposed architecture and protocol .

Specifically, an agent-based collaborative architecture will be developed for the purpose of providing more dynamic mobility support while a user roams and maintains an on-going connection or session over an IP-based network. The objective of the agent architecture is to provide an IP-based network such as the Internet with the flexibility and efficiency of mobile cellular networks, but without the extensive complexity. Essentially, the role of the collaborative agent architecture is to provide the network with the ability to exhibit 'intelligent' behaviour – awareness, dynamism and adaptation, in terms of user movement and requirements – perhaps surpassing those of present mobile architectures.

The approach used in this research is by incremental development of distributed intelligence in the proposed architecture. Intelligence will be realised through the use of software agents in the mobile host and in the edges network (at the access networks). Here, intelligence is defined collectively as the control mechanism as well as the ontology and task-oriented capabilities of the agents. The agents will be implemented from the middle to higher layers of the protocol stack.

The decision to provide intelligence by software agents and to place them at these layers is motivated by the following:

- possibility of specifying and relaying end-to-end user requirements via agents during movement;
- ability to provide service quality management, if needed;
- flexibility to provide customised services for each mobile user at a finer level of granularity; and
- possibility of implementing dynamic methods of adaptation through agents.

In this research, the proposed collaborative-agent architecture will be essentially a community of agents i.e. an agency that will negotiate service requirement, expedite location management and handover management requirements for mobile users over packet-based networks (options which are currently unavailable under Internet mobility). These agents will collaborate with each other to relay end-to-end user requirements to the network and to provide state information of mobile host(s) - e.g. location, and possibly application requirements - as it moves along different cells. Messages will be relayed to the relevant agents (i.e. home network agent, agents in the next-cell(s) etc.) who, in turn, will undertake appropriate tasks dynamically to ensure a smooth handover to the next cell(s) during an on-going application session. The main assumption is that the host's application and the network(s) are running over an IP-based architecture (or an architecture that supports IP) which, in turn, may consist of multiple domains or autonomous systems.

## 1.4 Scope of Research

The scope of research will encompass several areas of study namely, intelligent agent system modelling and development; mechanisms for mobility management; and evaluation of the proposed design.

Intelligent agent development will include agent design and role modelling, specifying agent types and characteristics, agent tasks definition and responsibilities, agent placement, agent architecture, degree of collaboration and mode of communication, type of messages, methods for passing messages, transport protocol, agent platform, agent coding etc (Chapter 3). The type, placement and behaviour of each agent will be specified so as to provide location and handover management as well as certain personalized service(s) for a typical mobile user. This would include specifying the agent communication to relay the appropriate messages. To this effect, an agent development platform would be used to establish the agent communication and the associated knowledge base.

The mechanisms for mobility support will be tightly integrated with the behaviour of the agents and the proposed services and enhancement offered by the architecture. Initially, a study of the different mobility management methods presently adopted in both the packet-based and circuit-switch networks will be investigated (as discussed in Chapter 2). Subsequently, appropriate mechanisms will be developed and these will be assigned as specific tasks and goals that will be performed by the relevant agents to maintain end-to-end user requirements along the mobility path. These mechanisms will collectively form the agent-based protocol for mobility management.

Evaluation will consists of two parts i.e. (i) validity and correctness of the agent interaction and messaging, and (ii) performance analysis of the architecture and protocol via mathematical models and simulation models. In the first part, a small prototype of the agency will be built using an agent development platform known as AgentBuilder Pro. The main criterion of this phase is to ensure the correctness of the agent interaction and messaging used for mobility management. Each agent will have its own ‘world view’ with specific tasks and goals to accomplish. The mode and degree of interaction are defined within this prototype. The agency’s interaction and communication are considered ‘correct’ or valid when the respective agents are able to accomplish their tasks and meet their goals.

The second part will focus of the performance of the proposed agent-based protocol, which encompasses the application, transport and the network layers of the TCP/IP protocol stack. A comparative analysis will be made using both mathematical models and simulation models to evaluate the AMP architecture and protocol. The use of mathematical models is desirable for accuracy and this further verified by building a prototype of the architecture over a network simulator such as ns-2. Finally, as part of the analysis, certain parameters will be investigated and they include signaling cost and overhead at connection request and during handovers, and packet loss and delay, where applicable, and these will be compared against the IETF's standard Mobile IP protocol.

The research will mainly concentrate on the middle to the higher layers of the protocol stack. Lower layer technologies i.e. data link and physical layers such as radio spectrum, access technology, and frequency division techniques, for example, are considered beyond the scope of this thesis and will not be addressed in this research. However, mobility management in GSM networks will be highlighted as a means of illustrating the location and handover management found in cellular architectures (see Chapter 2 on literature review). Specific security issues are also outside the scope of study since it is the aim of this research to develop an architecture that will not introduce additional security concern. Also outside the research scope is the implementation of 3G/UMTS networks since this would typically involve lower link layer protocols.

In addition, the proposed design will not address aspects pertaining to device-independent mobility (or *session mobility*); where a user may change from one type of mobile device to another during a single active session. Furthermore, protocol-specific solutions such as those used in the circuit-switched digital cellular environment (e.g. in handover management in SS7 network) will not be delved upon. In addition, support for micro-mobility will not be specific to any particular QoS protocol. The main reason for these is to examine and develop solutions that will be generic over any architecture that will support Internet mobility.

## 1.5 Significance And Contribution

The significance of this work and the potential contribution of research may be succinctly described as follows:

i. Development of a multi-agent system in the domain of mobility management
ii. A contribution towards the efficiency and of seamless mobility through the development of:
    a) a framework that amalgamates current approaches to seamless mobility into an architecture that utilises both mobile-aware host with an intelligent (via control mechanisms and ontology) and adaptive network;
    b) a new protocol for mobility management using collaborative agents that facilitates and improves user/node mobility over a packet- or IP-based network; and
    c) an improved IP-based architecture, operating primarily at TCP/IP's network layer and is transparent to both application and lower layers, and has lower latencies and packet loss than the standard network-layer mobility protocol from IETF i.e. Mobile IPv6 (as well as Mobile IPv4).

## 1.6 Thesis Layout

This thesis is divided into seven chapters. Chapter 2 provides an overview of literature that has been reviewed related to the area of research namely software agents and to a greater degree, mobile systems and mobility management architectures. It also includes related work in the area such as enhancements to Mobile IP.

In Chapter 3, the proposed agent system on the mobile host is developed. Using role modeling and collaboration diagrams, the agent system is defined, the agent communication specified and these are all subsequently built using an agent development platform called AgentBuilder Pro. The main purpose is to ensure the correctness of agent messaging since agents typically operate at higher layers with finer level of granularity (e.g. time and/or event-based cycle, mental or world view, knowledge representation, autonomy, performative acts, attributes etc.) – as such, agents and their behaviour may not be represented correctly using simulators since too many assumptions would have to be made.

Chapter 4 focuses on the specification of the multi-agent system in the network, known in this thesis as the agent-based mobility protocol or AMP architecture. Here, the placement of agents has been made at the edges of the networks i.e. in network nodes such as access routers. The mobility management protocol associated with AMP is designed and specified using operations diagrams in this chapter.

From the specifications, the AMP architecture is evaluated using derived mathematical models in Chapter 5. The analytical models were deduced from the operations of the AMP protocol and were based on similar works in the area. Here, the performance of AMP is compared against Mobile IPv6 for mobile QoS parameters, namely, signaling cost, packet delivery cost and latency.

In Chapter 6, the AMP architecture is built over a network simulator called ns-2. Here, special custom object classes had to be developed in order to simulate the behaviour of the proposed protocol and architecture. The existing wired-wireless protocol and architecture in ns-2 were extended and several simulation scenarios were run against Mobile IP as comparison. The simulation result was also compared to the result obtained from the derived analytical models. Finally, the thesis concludes in Chapter 7 with an overview of the work done and further work that may pursued in this area.